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Design and performance evaluation of a 5 kW producer gas stove

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ABSTRACT

The paper addresses the studies of a wood gas stove in meeting cooking energy requirement using biomass gasification. The stove works on natural draft mode. The thermal efficiency of the stove was recorded at about 26.5% and it can be started, operated and stopped with very low emissions. It can use a wide variety of biomass fuels. The produced wood gas burns with a blue flame like liquid petroleum gas with a flame temperature of 736 °C. The design criteria, safety measures and operating procedure of wood gas stoves are presented in this paper.

1. Introduction

Liquefied petroleum gas (LPG) is one of the conventional sources of fuel for cooking in a developing country like India. The use of LPG as a source of fuel is common both in the urban and in the rural areas, particularly in places where its supply is readily accessible. Since LPG is easy to control, convenient to operate and clean to use through emission of blue flame, therefore it is widely adopted for household use. However, because of the continued increase in the price of oil in the world market, the price of LPG fuel has gone up tremendously and is continuously increasing at a fast rate. Typically a household of two adults and four children will consume one 15 kg tank of LPG costing \$7.5 (exchange rate Rs. 40 $\$^{-1}$, May 2007), every 20–30 days depending on the number of meals and quantity of food. Further, the local fuel price is \$4 GJ^{-1}, which is about 40% of the LPG cost. Keeping in view problems related to availability, price of LPG fuel, research centers and institutions are challenged to develop a technology for cooking based on alternative energy sources other than LPG. Biomass is the main source of domestic energy requirement in developing countries. However, low-cost biomass as a solid fuel provides very poor performance environmentally; pyrolysis and gasification can make it more equivalent to LPG for the end user [1–3]. In order to use biomass in a thermal conversion mode, appropriate designs of biomass stoves are needed. Traditional biomass cookstoves have low thermal efficiency and high flue gas emission compared to improved cookstoves [4–7]. The wood gas stove has the potential to replace LPG stoves since the combustion of the gaseous mixture of CO and H_2 can be complete, thus minimizing the emissions of products of incomplete combustion (PIC), which is a major problem with solid fuel combustion [8]. The wood gas stove works on the concept of natural draft gasification. Apart from being fuel efficient, gasifier stoves have low emission in comparison to traditional cookstoves [9–14]. Traditional cookstoves, because of their very low efficiency, emit more than 10% of their carbon as PIC, comprising varying amounts of tar. In addition, about 100–180 g of carbon monoxide and 7.7 g of particulate matter are also emitted per kg of wood. Gases such as methane, total non-methane organic compounds and N_2O are also added to this. These PIC emissions

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Nomenclature

Q_n	energy needed ($MJ\,h^{-1}$)
CV	calorific value ($MJ\,kg^{-1}$)
FCR	fuel consumption rate ($kg\,h^{-1}$)
η_g	gasification efficiency
D	reactor diameter (cm)
SGR	specific gasification rate ($kg\,m^{-2}\,h^{-1}$)
ρ_{wood}	wood density ($kg\,m^{-3}$)
T	duty hour
$MNRE$	Ministry of New and Renewable Energy

are even higher in the case of loose biomass or cow dung used as fuel in these traditional cookstoves [15].

2. Materials and method

Wood gasification is the process of converting fuel wood into combustible carbon monoxide by thermo-chemical reaction of the oxygen in the air and the carbon available in biomass. In complete combustion of fuel, the process takes place with excess air. The gasification process, on the other hand, is accomplished with excess carbon as partial combustion. In order to gasify woods, about 30–40% of the stoichiometric air (6.0 kg of air per kg of wood) is needed [16]. Commercially viable gasification has long been understood and used in the industry and even in transportation, but not for small applications such as a household stove. Gasification of wood (or other biomass) offers the possibility of cleaner, better controlled cooking gas for the developing countries. Wood gas stoves offer the advantages of "cooking with gas" while using a wide variety of biomass fuels. The emissions from the close-coupled gasifier–burner are quite low and the stove can be operated indoors [17]. The system has been developed keeping in view its suitability for Indian conditions. The inexpensive wood gas stoves can bring the "joy of cooking with gas" to everyone while using a wide variety of renewable biomass fuels or coal [18–20].

2.1. *Biomass for testing*

Babul wood (*Prosopis juliflora*) was selected as feedstock for testing of wood gas stoves. The babul wood was cut into small pieces as mentioned in Table 1 and stored in a dry place for further use. Proximate analysis of fuel was carried out before the test by using the method suggested by ASTM [21]. The calorific value of feedstock was also measured by a digital bomb calorimeter (Advance Research Instrument Company). The physical and thermal properties of feedstock used for testing purposes are given in Table 1.

2.2. *Design of wood gas stove*

The fabrication of the stove was made using inexpensive local materials as per theoretical design. This developed wood gas stove offers efficient applications, which make renewable energy devices user friendly and sustainable in the rural society [22]. The system was designed in the following manner:

(a) *Energy needed*: The amount of energy needed to cook food for a family of six members is estimated as

$$Q_n = 15.8\,MJ$$

(b) *Energy input*: This refers to the amount of energy supplied by the fuel fed into the stove having a calorific value of $15.5\,MJ\,kg^{-1}$. This can be computed using the formula

$$FCR = \frac{Q_n}{CV \times \eta_g}$$

$$Q_n = \frac{15.8}{15.5 \times 0.70} = 1.45\,kg\,h^{-1}$$

(c) *Reactor diameter*: The diameter of reactor is calculated by using following formula:

$$D = \left[\frac{1.27FCR}{SGR}\right]^{1/2}$$

$$D = \left[\frac{1.27 \times 1.45}{90}\right]^{1/2} = 14.3\,cm$$

Hence, the diameter of gas stove was taken as 16 cm.

(d) *Height of the reactor*: It can be computed by using the following formula:

$$H = \frac{SGR \times T}{\rho_{wood}}$$

The height of the gas stove was computed as 31.5 cm. However, the actual height of the system was kept at 41.5 cm

Table 1 – Physical and thermal properties of feed stock babul wood (*Prosopis juliflora*)

Sl. no.	Characteristic	Biomass (babul wood) (*P. juliflora*)
1	Size (mm)	15–20
2	Length (mm)	30–50
3	Bulk density ($kg\,m^{-3}$)	285
4	Angle of slide (deg)	15
5	Moisture content (% wb)	10.2
6	Volatile matter (% db)	83.42
7	Ash content (%db)	1.05
8	Fixed carbon (%db)	15.53
9	Calorific value ($MJ\,kg^{-1}$)	15.5

to obtain the proper mixing of secondary air for obtaining full combustion of the producer gas. The schematic line diagram of designed stove is presented in Fig. 1.

Critical insulation thickness of Insulyte 11U from Mahavier Refractories Corporation was held by mild steel anchors welded to the outer shell. Prior to use, the refractory was cured for 24 h.

3. Result and discussion

3.1. *Performance of stove*

The water boiling test was carried out as per the protocol of the Ministry of New and Renewable Energy, Government of India, to evaluate the thermal performance of the system. The thermal efficiency of wood gas stoves was calculated as 26.5%, which is close to 27% as reported by Bhattacharya [23].

The fire hole of stove was filled with dried fuel wood to within 5 cm of the top. It is desirable to have the uniform spread of fire laterally across the surface to provide heat over the whole area. This was accomplished by putting a combustible material, such as diesel-soaked cotton jute, grease, etc. initially on top of the fuel bed. Once it ignites from top, it gives combustible gas (producer gas) and a blue flame is established within 5 min of ignition. It has been observed that the stove burns continuously for 41 min as illustrated in Plate 1. During the testing, temperature of the outer surface of stove was recorded as about 105 °C, which indicates that there is still a chance to minimize conduction and radiation heat losses from the outside skirt of cookstoves. The flame temperature was recorded by a K-type thermocouple and it was about 736 °C during the peak hour of combustion.

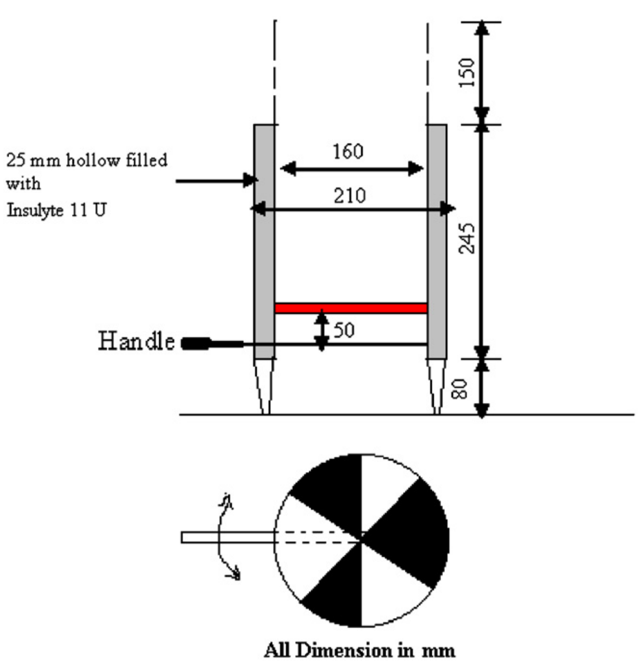

Fig. 1 – Line diagram of wood gas stove.

Plate 1 – Wood gas stove flame.

3.2. *Emission from stove*

Emission of pollutants from biomass fuel during combustion depends on the quantities of fuel consumed and type of combustor used. Domestic cooking is a major source of emission from biomass. However, with increase in the efficiency of stove, the amount of CO_2 and CO emission inside the kitchen has been reduced, which was measured at a distance of 1 m from wood gas stoves with the help of gas analyzers (AFRISO EURO INDEX, Multilyzer Industries). It was found in the range of 18–2 and 1–3 ppm respectively and within safe limits as recommended by the WHO [24].

3.3. *Safety during operation*

The outside temperature of the stove during testing was recorded as 105 °C, which can burn users, so it is recommended to use a handle when moving or handling a hot stove. During the operation of the stove, carbon monoxide was obtained, which is toxic in nature. Therefore, it is recommended not to use the stove in an enclosed area, i.e. in a tent, camper or in a house. Subsequently after completion of the burning period some charcoal is obtained as unburned fuel. If the stove is closed before charcoal is fully consumed, there are chances that the charcoal remains a fire hazard. Disposal of the charcoal in a safe place where it does not produce a fire, or waiting until it cools to a safe temperature [25], is also an important requirement in operating a stove.

3.4. *Source of availability*

An entrepreneur in Udaipur (M/s Matri Kripa Engineering Works) has been identified and trained by the department to

fabricate the wood gas stove. The entrepreneur has fabricated more then 30 units and installed them in various roadside hotels and tea stalls in Udaipur district. The production cost of each unit is about $15.6 and it increases with capacity. More details on the technology including training to rural artisan can be provided by the university.

4. Conclusions

This type of stove has the potential to save fuel wood because it can work on a great variety of non-wood or waste-wood fuels. The combustion efficiency and heat-capture efficiency of stoves are better than efficiencies of open fires and stoves currently in use, resulting in the need for less fuel. There are millions of small and inefficient cooking fires needed to feed economically poor people. Society needs an efficient stove that does not pollute, and the small wood gas stove is one of these, and quite possibly the best of these.

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